A MODEL FOR FORECASTING POLLUTION
PREVENTION LIFE CYCLE COSTS
FOR AIR FORCE MAJOR WEAPON SYSTEMS

THESIS

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Captain, USAF   First Lieutenant, USAF

AFIT/GCA/LAS/95S-2

DEPARTMENT OF THE AIR FORCE
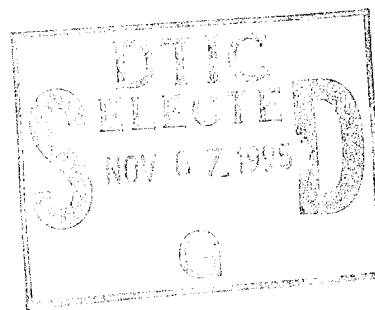AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty of the Graduate School

of Logistics and Acquisition Management

of the Air Force Institute of Technology

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Cost Analysis

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Table of Contents

List of Figures

List of Tables

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Abstract

This research effort developed a modification to the HAZMAT program so that the program could provide the user with the capability to generate an estimate during the concept exploration and design phases for the total costs associated with hazardous materials usage in a major weapon system. Using the HAZMAT database, a spreadsheet was developed which projects a cost for a weapon system based on its total surface area and the number of aircraft to be produced by performing an analogy with a similar weapon system. The modification uses algorithms which are based on the hazardous material substances rather than processes which use hazardous materials. This enables the user to eliminate various substances entirely from the weapon system rather than trying to identify every process which uses a particular substance.

The modification was identified to be the most efficient method of calculating an estimate during the early phases of the life cycle through in depth interviews and analysis of existing literature on the subject. The authors feel that the methods discovered in this thesis will provide insight for future revisions of HAZMAT and new attempts to formulate a life cycle cost model for hazardous materials.

A MODEL FOR FORECASTING POLLUTION PREVENTION LIFE CYCLE COSTS FOR AIR FORCE MAJOR WEAPON SYSTEMS

I. Introduction

General Issue

The Air Force faces a major problem in trying to estimate Life Cycle Costs (LCC) for major weapon systems, especially the LCC of Hazardous Materials (HM). LCC is the total cost of a program associated with the "cradle to grave" management of the system. A large part of the problem is that estimates are required in the initial stages of conceptualization when designs have not yet been specified. It is important that the program manager be able to obtain a reasonable estimate of LCC during the early phases of development in order to justify the development and acquisition of the system.

Major acquisition projects are separated into different component groups which have the same general interest, such as engines, avionics, weapons control and environmental issues. These component groups are called support divisions and they are responsible for issues within their interest. Many of the support divisions have developed adequate models to forecast their portions of the total LCC. However, the environmental division does not have an adequate tool to forecast the program costs of dealing with hazardous materials (HM).

The LCC of HM usage in the weapon system can capture a large portion of the total LCC; legal/environmental, personal protection, and disposal cost of hazardous materials averaged 71 percent of the life cycle cost of a weapon system (1:11). In a study completed by the Air Force's Hazardous Materials Management Task Force at the Human Systems Division, they discovered that over a 20 year operational lifetime of the F-16 fleet, HM will cost 750 million dollars. With the B-1 fleet, HM cost is 500 million dollars (3:2-12). These large costs make it necessary for a model to be developed which would allow the HM usage costs to be forecast during the early stages of weapons system development.

There are various cost models available (these models are discussed later in Chapter 2) that attempt to estimate the cost of using HM in a system, but only one which attempts to estimate the LCC of HM. This model is the Hazardous Materials Life Cycle Estimator (HAZMAT), developed by The Analytical Sciences Corporation (TASC) for the United States Air Force (1:41). According to the User's Guide,

> *The system is designed for System Program Office, contractor, and repair depot personnel to assess the cost of using hazardous materials in current and future weapon systems. (7:2-1)*

TASC used historical data provided by the USAF on the F-16 fighter, B-1 Bomber, and aircraft engines to develop the model (7:4-1). According to Dr. John A. Long, Department Staff Analyst for TASC, the model has proven to be accurate

to within the five to fifteen percent range. The USAF has also used the model on other projects, such as the F-15 and Titan missile. In an interview with Dr. Long, he revealed that the model was helpful provided the project had progressed to the point where accurate descriptions of the materials needed were available. The users of this program are currently required to enter site-specific and operation-specific cost data (8:22); therefore, most practitioners in the field have been unable to incorporate this tool into their efforts to do hazardous materials tradeoff analyses.

Research Objectives

The current void in weapon systems' analysis is being able to come up with an estimate for hazardous materials in the early phases of the acquisition process (Demonstration/Validation). However, the regulations dictate that a cost estimate should be formulated during this phase. The HAZMAT costing model needs to be further refined so that environmental analysts and program managers can obtain reasonable LCC estimates in the early phases of the acquisition process without knowing site-specific and operation-specific information. The purpose of this research is to develop parameters that will allow the HAZMAT user to run the program with limited information without losing a significant degree of reliability. Specifically, we plan to develop cost estimating relationships (CER) with a limited number of independent variables.

3

Investigative Questions

In order to develop accurate cost estimating relationships that allow the database of the HAZMAT program to be utilized the following questions must be answered:

(1) What information is available in the database maintained by HAZMAT?

(2) What information do environmental analysts and program managers have about the weapon system before the design is specified?

(3) What are the major cost drivers for hazardous materials usage?

(4) Do the available independent variables adequately capture the costs associated with hazardous materials usage? The answers to these questions will help us to identify and specify the cost drivers for our CERs.

Definition of Terms

The following definitions will aid in evaluation of unfamiliar terms.

Acquisition Pollution Prevention - The activity to reduce and/or eliminate pollutants before a system enters operational service, and the "re-engineering" of the system to eliminate or mitigate the environmental , safety, and occupational health impact of a fielded weapon system (3:10).

Cost Estimating Relationship (CER) - a mathematical relationship that relates one variable, usually cost (called the dependent variable), to one or more other cost drivers called the independent variables (24:23).

Hazardous Material (HM) - The operational definition of HM is taken from Mitre Corporation's report on the Acquisition of Hazardous Materials (AMHM). Mitre Corporation defines HM as:

Any material which is mission-critical to weapon systems acquired by the Air Force and because of the material's physical, chemical, or biological characteristics; quantity; or concentration may:

>(a) Cause or contribute to adverse effects in organisms or offspring;

>(b) Pose a substantial present or future damage to the environment;

>(c) Result in damage to or loss of equipment or property during the system's life cycle (development, testing, manufacture, operation, maintenance, modification, and disposal). (5:2-4)

HM Cost - The life cycle costs associated with all facets of use of a hazardous material including the following cost factors: procurement, transportation, handling, management, training, personnel protection, legal/environmental liability, medical, facilities, support equipment, emergency response, and disposal (1:11).

Life Cycle Cost (LCC) - The estimated total direct, indirect, recurring, nonrecurring, and other related costs in the design, development, production (26:3).

Major Defense Acquisition Program - An acquisition program that is designated or estimated by the Under Secretary of Defense for Acquisition to require:

>(a) An eventual total expenditure for research, development, test, and evaluation (RDT&E) of more than $200 million if FY80 constant dollars (approximately $300 million in FY90 constant dollars), or

>(b) an eventual total expenditure for procurement of more than $1 billion in FY80 constant dollars (approximately $1.8 billion in FY90 constant dollars). (12:2)

Pollution Prevention - Reducing the amount of unwanted wastes and pollution generated by manufacturing processes,

so there is no handling, treatment, or disposal required (12:3). It incorporates changes to the design (the way we develop a system), manufacture (the way we make a system), and maintenance (the way we support a system).

Conclusion

In this chapter we have tried to familiarize the reader with the need for a life cycle cost estimator (LCCE) dealing with hazardous materials. Definitions of unfamiliar terms were introduced along with a discussion of HAZMAT, the LCCE model provided by TASC to the USAF. In the next chapter we discuss the findings of our literature review of the materials relevant to this research.

II. Literature Review

Overview

The growing interest in hazardous materials and their role in the acquisition process has been spurred by increased environmental regulations and guidance and the discoveries which have led to cutting edge pollution prevention techniques. The interest in these hazardous materials has generated the need for the Air Force to develop cost models to estimate the cost of using hazardous materials in weapon systems. This literature review focuses on exploring environmental regulations and guidance, pollution prevention programs, and existing hazardous materials cost models.

Environmental Regulation and Guidance

The Air Force faces a shrinking budget and increasing responsibility for its actions. In order to avoid future financial hardship, the Air Force is actively trying to avoid long range problems by decreasing the amount of HM usage in major weapon systems. The current focus on pollution prevention is driven by the numerous federal environmental regulations presented in Table 1.

TABLE 1

KEY ENVIRONMENTAL LAWS

- National Environmental Policy Act (NEPA) - developed in 1969
- Occupational Safety and Health Act (OSHA) - developed in 1970
- Clean Air Act (CAA) - developed in 1970 and amended in 1977
- Clean Water Act (CWA) - developed in 1972
- Toxic Substances Control Act (TSCA) - developed in 1976
- Resource Conservation and Recovery Act (RCRA) - developed in 1976

- Hazardous Materials Transportation Act (HMTA) - developed in 1976 and last amended in 1990
- Comprehensive Environmental Response, Compensation & Liability Act (CERCLA) - developed in 1980
- Superfund Amendments and Reauthorization Act (SARA: an amendment to CERCLA) - developed in 1986
- Pollution Prevention Act of 1990

The Resource Conservation and Recovery Act (RCRA), the Clean Air Act (CAA), and the Occupational Safety and Health Act present the biggest challenges to the Air Force and weapon system contractors, although compliance to all regulations is required (3:2-5). The Resource Conservation and Recovery Act (RCRA) prohibits land disposal of untreated hazardous wastes. The Clean Air Act (CAA) requires installation of "maximum available control technology" and operating permits for numerous pieces of industrial equipment that produce air emissions (3:2-7). The Occupational Safety and Health Act requires that "no employee will suffer material impairment

of health or functional capacity" from a lifetime of occupational exposure (3:2-8).

The Pollution Prevention Act of 1990 (Executive Order 12856) encouraged Air Staff to publish the Air Force Policy Directive 19-4, which established the Air Force pollution prevention policy. The Pollution Prevention Act established a hierarchy of options; source reduction, recycling, treatment, and disposal as a last option (19). The Air Force policy directive included the same hierarchy of options for the Air Force. Objective 1 of the Policy Directive is broken down into the following sub-objectives:

- *By the end of 1994, institutionalize pollution prevention including hazardous materials minimization and management into the system acquisition process (concept, design, development, modification, maintenance and ultimate disposal) through the use of policies, procedures, training, contract provisions, and Federal Acquisition changes.*

- *Develop and incorporate procedures into system development milestone criteria that require: (a)Identification of hazardous materials, evaluation of environmentally acceptable alternatives, and selection of alternatives where indicated by life cycle analysis; (b)Identification of the remaining hazardous materials and the alternatives considered and reasons for their rejection; and (c)Estimates of the quantities of each hazardous material needed through the lifetime of the system; based on the most current concept of operations.*

- *Identify hazardous material use and waste generation for all acquisition programs, starting with C-17, B-2, T-1, HARM, TITAN-IV, Peacekeeper, JSTARS, and LANTIRN.*

- *Institute policies and procedures to reduce the use of ozone depleting chemicals 50% by 1995 from 1992 baseline,*

*and eliminate the need to purchase ozone depleting
chemicals by 1997.*

● *Replace hazardous material requirements in new system
  TO's, MILSPECS and MILSTDS with environmentally
  acceptable alternatives. Where none exist, prioritize
  the uses, select the ones with the highest potential
  improvement, and conduct a Science and Technology or
  Manufacturing Technology effort to develop alternatives.*

● *Identify material and process substation needs critical
  to achieving pollution prevention objectives for
  integration into the Science and Technology Program.
  Obtain the resources required to accomplish the
  objectives. (21)*

In 1991, the Defense Department issued two documents on
environmental policy and procedures in an effort to
eliminate environmental problems associated with new weapon
systems throughout the military. DODI 5000.2 and DOD Manual
5000.2 require program managers to address environmental
concerns at each step of the acquisition process. The
potential environmental effects of each alternative should
be assessed during the Concept Exploration and Definition
Phase and the substantial effects noted. The initial
assessment should begin as soon as mission needs are
determined and be completed prior to Phase I, Demonstration
and Validation. DODI 5000.2, Part 6, Section I requires the
integration of pollution prevention into the systems
engineering and compliance with NEPA. NEPA became law on
1 JAN 70 and the procedural provisions were issued on
29 NOV 78. It requires impact consideration before taking
action, a public comment period, and preparation of "formal"
documents.

The Department of Defense Directive 5000.2 requires documentation of potential environmental consequences with a Master Plan called a Programmatic Environmental Assessment (PEA) which is usually originated during Phase 0 and updated at each milestone. The PEA includes a description of the program and phase; the alternatives to be studied; the potential environmental impacts; and the impact of alleviation procedures on schedule, cost, and site choices. The PEA is one of seven annexes to the Integrated Program Summary (IPS). The PEA is a program document, not a formal NEPA document. The PEA has two purposes: provides the Single Manager and the decision authority the information to make decisions early on, and it identifies NEPA compliance requirements and provides the data for the NEPA documentation. Figure 1 shows how the PEA, the Test and Evaluation Master Plan (TEMP) and the Integrated Logistics Support Plan (ILSP) incorporate Environment, Safety and Occupational Health (ESOH) issues into the acquisition strategy of a program.

The Test and Evaluation Master Plan (TEMP) should address the health hazard and safety critical issues to provide data to validate the results of system safety analyses. The Integrated Program Summary should assess the system safety, health hazard, and environmental risks that cannot be corrected or mitigated through system design changes or new technology and identify what residual hazards must be accepted by formal decision (12:6-I-5).

11

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┌─────────────────────────────────────────────────────────┐
│         PROGRAMMATIC ENVIRONMENTAL ANALYSIS               │
│                      (PEA)                                │
│       (AN ELEMENT OF THE ACQUISITION STRATEGY)            │
│                                                           │
│                ┌──────────────────────────┐              │
│                │   ACQUISITION STRATEGY   │              │
│                └──────────────────────────┘              │
│  PROGRAM                                                  │
│  MASTER      ( TEMP )    ( ILSP )    ( PEA )              │
│  PLANS                                                    │
│                                                           │
│            ┌────────────────────────────────────┐        │
│  RISK      │   COST, SCHEDULE, PERFORMANCE,      │        │
│ MANAGEMENT │  SUPPORTABILITY, SYSTEM SAFETY,     │        │
│  ISSUES    │   POLLUTION PREVENTION, ETC.        │        │
│            └────────────────────────────────────┘        │
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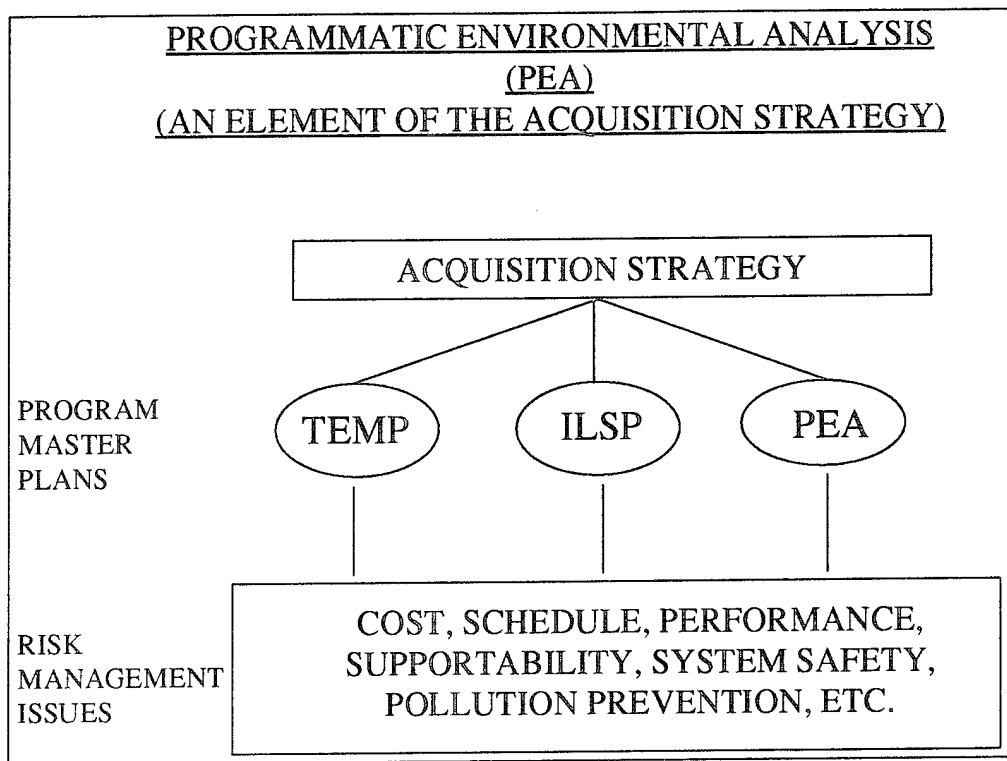
FIGURE 1 Programmatic Environmental Analysis

The Air Force is realizing that pollution prevention
can ease the compliance challenge (3:2-5). To help program
managers and analysts in their job of dealing with HM, the
Air Force has published three volumes which condense the
information in the plethora of Federal and DoD regulations
pertaining to pollution prevention. The first volume is the
Acquisition Pollution Prevention: AFMC Implementation Guide.
This guide discusses how Air Force Materiel Command (AFMC)
is structured to deal with pollution prevention and
"identifies key elements of acquisition pollution prevention
that should be considered" (1:9). It also discusses the
tools available for managers and analysts to aid them in

pollution prevention. One of the tools it discusses is the HAZMAT Model. According to the guide, "Life-cycle cost estimates for alternative materials and processes are needed to meet the requirements in Volume II of this package. No other life-cycle cost model currently exists to do this function(1:41)."

The Implementation Guide also provides program managers with direction concerning the organizational structure set up in the Air Force to monitor pollution prevention. The following section will address these organizations.

Pollution Prevention

The Air Force Pollution Prevention Program (PPP) and the Acquisition Management of Hazardous Materials Program (AMHM) are the two primary governing systems for pollution prevention in the Air Force. The Environmental Regulations Guide for Weapons Systems Managers (Volume II, mentioned in the last paragraph) talks about these two programs and summarizes the appropriate Federal and DoD regulations which govern the administration of these programs. The Air Force PPP deals with the use of hazardous materials in weapon systems and non-weapon system operation.

The AMHM program is designed to evaluate HM in weapon systems only. The AMHM program was developed as a result of a preliminary study on the HM acquisition process performed by the Mitre Corporation (23:1-1). The purpose of this study was to evaluate the hazardous material acquisition

process and to make recommendations to reduce the cost of hazardous material management (23:1-1). The objective of the AMHM program is to provide oversight to ensure that life cycle cost considerations are given to HM in each phase of the weapon system acquisition process (28:1).

A strategic goal of the Pollution Prevention Program is to "prevent future pollution by reducing hazardous material use and releases of pollutants into the environment to as near zero as possible"(26:2). When HM usage cannot be eliminated, "find alternate materials and processes, and ensure their life cycle costs are evaluated"(2:15). For the Air Force, pollution prevention must start with the design of the weapon system (1:ii). Objective 1 of the Pollution Prevention Action Plan specifically states that the life cycle costs of alternative materials and processes for HM should be measured. The milestones criteria require the selection of alternatives based on life cycle cost analysis (26:2).

The high costs of HM need to be addressed during the development of the weapon system. If the use of the HM can be eliminated or at least reduced, the savings in the future can be very significant. Increased investment during the design and production phases can lead to large cost reductions over the life cycle of the system due to decreased operational costs and disposal costs. The Air Force's Hazardous Material Management Task Force at the Human Systems Division performed a study that revealed that

the incremental costs of managing HM, just for the airframe, over a 20 year operating life of the total fleet was on the order of 750 million dollars for the F-16 and 500 million dollars for the B-1 (3:2-12). The study researched the F-16 fighter and B-1 bomber, and it only addressed the costs associated with managing hazardous materials during the operation and maintenance phases of a system's life cycle. Failure to address the HM characteristics early in the development of a weapon system can result in the incorporation of a costly and dangerous element in the system design as evidenced with hydrazine and the F-16 (1:2-15).

The following problems resulted due to poor lack of consideration for the effects of hazardous materials usage in the emergency power unit of the F-16. The emergency power unit (EPU) of the F-16 provides emergency electrical and hydraulic power to the aircraft in case of engine failure. The EPU uses a mixture of hydrazine and water as the fuel to power the unit. Approximately 6.8 gallons of this mixture are stored in a stainless steel tank on board the F-16. According to the Royal Danish Air Force Medical Service,

> Hydrazine is a powerful reducing agent which is known to be toxic to human beings whether absorbed by inhalation or ingestion or through the skin. As little as 10-15 cc of hydrazine are considered dangerous when left in contact with the skin for just a few minutes. (17:3-1)

15

The result of using this type of EPU with hydrazine requires that maintenance personnel receive special training and use special clothing when working with the EPU. Also, personnel working with hydrazine are required to receive special medical monitoring(17:3-1). All of these procedures generate unnecessary expenditures over the life cycle of the F-16 that would not have been present if the designers had used a different EPU with environmentally safe technology. If the designers had used a tool that showed the cost of using hydrazine over the life cycle of the F-16, they may have chosen a different technology that could have avoided HM costs over the life of the system.

Training

The USAF Scientific Advisory Board, in 1986, identified numerous problems with HM management in the Air Force. One of their findings states that the System Program Offices (SPO), which manage the acquisition of major Air Force weapon systems, do not have the training nor the technical support to accurately assess the financial impacts of HM usage (24:415). Although training programs have been developed, there has been little standardization of procedures for generating LCC estimates, especially for estimates required during initial development. It is imperative that a model be formed that will aid analysts in preliminary forecasts of the LCCs of various alternatives for HM, because most of the decisions made in the early

16

phases of the acquisition process become extremely costly to change in later phases.

Air Force Approved Hazardous Material Cost Models

Air Force Directive 19-4 dictates that if HM cannot be eliminated, then the Air Force must select HM based on LCC analysis. This means that if a HM must be used as a component of a weapon system or in a process to build or maintain that weapon system, then LCC analysis must be used to show that the cost of this component or process is justified. However, neither the AMHM Program nor the Air Force PPP provides any written guidance on how to calculate the LCC. The current tools being used in the Air Force for pollution prevention in acquisitions are the Hazardous Material Life Cycle Cost Estimator (Version 3.0), Pollution Prevention Road Maps, and the Funding Estimator for Pollution Prevention Projects (16:1-2). The HAZMAT model is the only one of these tools that is capable of computing life cycle costs and generating estimates for cost trade-off analysis. Table 2 presents a summary of these tools and detailed descriptions follow.

TABLE 2

AIR FORCE POLLUTION PREVENTION TOOLS

Tool	Source & Date Developed	Purpose	Limitations
HM Life Cycle Cost Estimator HAZMAT	HSC/EMP Brooks AFB, TX Completed: 1994	Estimates life cycle costs for the use of HAZMATs for cost trade-off analysis.	Requires too many inputs for practical uses in acquisition work.
MAPS - Pollution Prevention Roadmaps	SM-ALC/EME McClellan AFB, CA Completed: 1994	Provides a management action plan for pollution prevention programs.	Does not provide cost information for management decisions or tradeoff analyses.
Funding Estimation Tool	HSC/EM Brooks AFB, TX Completed: 1994	Estimation of funding requirements for pollution prevention efforts.	No life cycle cost capabilities for tradeoff analyses .

HMLCCE (HQ AFMC) - HM Life Cycle Cost Estimator provides a system to estimate life cycle costs for the use of HAZMATs for cost trade-off analysis. It consists of four initiatives: a tool for cost trade-off analysis of hazardous materials, a tool to calculate the cost of maintenance processes/material costs, integration of HM LCCE and the Support Analysis Record (LSAR), and integration of HM LCCE into "Bluebook" Sensitivity Analysis. Requirement: 23 December 1993. POC: HSC/EMP 8213 14th St. Brooks AFB, TX.

MAPS - Pollution Prevention Roadmaps (HQ AFMC) - This model is a management action plan and set of integrated tools for pollution prevention. "MAP3 is a management strategy and set of management tools for pollution prevention programs." The program and software were developed specifically for McClellan AFB's Pollution Prevention program by MITRE Corp. Although the product was developed for a facility-type program, the principles and associated software which it incorporates have been adapted for use in individual weapon system pollution prevention programs. "It gives the Single Manager insight into facility-type pollution prevention programs and goals upon which their weapon system will ultimately have impact." MAP3 consists of a Management Action Plan for pollution prevention, three software programs and a set of "Road Maps" for use in evaluating the program. Requirement: SAF/AQ Policy Memorandum of 93M-011. POC: SM-ALC/EME McClellan AFB, CA.

FUNDING ESTIMATION TOOL (HQ AFMC) - This tool provides an algorithm which can be used in estimating funding requirements for pollution prevention efforts using historical depot, laboratory and product center data pertinent to the types of workload of the Center using the model. POC: HSC/EMP 8213 14th St. Brooks AFB, TX.

Other Hazardous Material Cost Models

Four other LCC models were discovered in our research:
the Life Cycle Design Model (EPA), the Pollution Prevention
Model (Rankin and Mendelsohn), Waste Cost Analysis Model
(DOE), and the Life Cycle Cost Decision Support Model
(Burley and Phillips). Table 3 presents a summary of these
models and descriptions of the models follow.

TABLE 3

LIFE CYCLE COST MODELS

Model & Date Developed	Purpose	Limitations
Life Cycle Design Model (EPA) Revision Completed: 1993	Enables user to evaluate the LCC of a product from cradle to grave.	Requires much previous knowledge about the material in question and is not applicable to many Air Force products.
Pollution Prevention Model (Rankin and Mendelsohn) Completed: 1992	Provides a systematic method to determine the costs and benefits of a proposed pollution prevention alternative.	Does not include all of the cost categories involved in the total life cycle of a hazardous material in an Air Force operation.
Waste Cost Analysis Model (DOE) Completed: 1992	Calculates the LCC of a hazardous waste.	Not appropriate for Air Force uses due to differences in operations and types of waste generated.
Life Cycle Cost Decision Support Model (Burley and Phillips) Completed: 1993	Calculates the LCC of using baseline hazardous materials.	Requires site specific cost data in order to make the calculations.

The Life Cycle Design Model (EPA) evaluates the LCCs of
a product from the acquisition of the natural resources to
the ultimate disposal of the finished product (12:19). The
model does not specifically generate the LCCs of HM, and it
focuses on production rather than services. The Pollution
Prevention Model (Rankin and Mendelsohn) was developed for a
Master's Thesis at the Air Force Institute of Technology.

20

It contained many cost categories and would not be easy to use without detailed requirements about the HM. The Waste Cost Analysis Model (Department of Energy (DOE)) calculates the LCCs for various types of DOE waste. This model would be hard to use in the Air Force since the types of waste generated by the Air Force significantly differ from those of the DOE. The Life Cycle Cost Decision Support Model (Burley and Phillips) was developed from a case study of the Tissue Processing operation at Brooks AFB, Texas. This model is a twelve step decision support model which focuses on tradeoff analyses and not on computing the best LCC possible (9).

HAZMAT Model

   Development.

   The material for this section was taken from the Hazardous Materials Management Life Cycle Cost Model Phase I written by TASC. The HAZMAT model was developed in two phases. During Phase I, TASC conducted three case studies of evaluation of weapon systems, assembled comparable cost information for alternate hazardous and nonhazardous materials in those systems, identified cost drivers, and proposed an architecture for a Hazardous Materials Management Life Cycle Cost model. During Phase II, TASC refined the model requirement parameters, developed the cost estimating relationships (CERs), and assembled the design and program for delivery to the Air Force.

The research accomplished during Phase I only included the B-1, the F-16, and aircraft engines. The F-16 was chosen because it satisfied a list of primary criteria established by TASC and had a known hazardous material problem due to the use of hydrazine as the fuel for the emergency power unit (EPU). The B-1 was chosen because it satisfied the primary criteria and it contained a high percentage of composite materials. Although aircraft engines are not a primary weapon system, the engines met all of the primary criteria and two of the Air Logistics Centers (ALCs) being visited performed engine maintenance. TASC had tentative plans of using the F-15 to validate the model if the Air Force awarded the validation contract to them.

The key to the data collection effort was the availability of historical cost data. The cost database was to include costs incurred throughout the life cycle of the weapon system - development, production, operating and support, and disposal. The case studies were supposed to identify when and how hazardous materials management costs were estimated and compare cost estimates for hazardous materials management that were prepared during the acquisition process with actual expenditures throughout the life cycle. Acquisition phase information was collected from the prime contractors because it was unavailable from the System Program Offices.

During Phase I, TASC conducted their research under the following ground rules and assumptions (7:2-3):

The cost analysis begins with the purchase of the hazardous materials by the Government. This is essentially the boundary of the problem. This study is not concerned with the process and hazards encountered in the production of the hazardous materials.

The operating locations visited are assumed to be typical of all B-1 and F-16 operating locations.

The Air Logistics Centers visited are assumed to be typical of all Air Logistics Centers.

The costs due to hazardous materials were calculated for one year that was assumed to be typical for the weapon systems under consideration. This cost was assumed to be constant for each year in the economic life duration of the weapon systems.

TASC formulated a cost element structure that was approved by the government. In order to identify the different phases of the life cycle cost, a cost element numbering system was used. Table 4 illustrates the cost element numbering system.

TABLE 4

COST ELEMENT NUMBERING SYSTEM

Phase	Cost Element Number
Development	1.0
Production	2.0
Operating and Support	3.0
Disposal	4.0

Each cost element in the Operating and Support Phase was

evaluated in the case study and a cost calculation was

formulated for modeling the cost. The Operating and Support

phase cost element structure used the format in Table 5.

TABLE 5

OPERATING AND SUPPORT COST ELEMENT STRUCTURE

Cost Element Number	Cost Element
3.1	Procurement
3.2	Transportation
3.3	Handling
3.3.1	Personnel handling
3.3.2	Lost productivity
3.4	Monitoring
3.5	Training
3.5.1	Personal protection training
3.5.2	Hazardous communication training
3.5.3	HW site manager training
3.5.4	Hazardous communication zone training
3.5.5	Hazardous communication training for supervisors
3.5.6	F-16 hydrazine spill & clean-up training (F-16 only)
3.6	Personal protection
3.6.1	Equipment
3.6.2	Dispensing and tracking
3.6.3	Lost productivity
3.7	Legal and Environmental
3.7.1	Toxic torts
3.7.2	Regulatory authority correspondence
3.7.3	Real property damage
3.7.4	Contaminated water treatment
3.7.5	Natural resource damages
3.8	Medical
3.8.1	Occupational physical examinations
3.8.2	Surveillance
3.8.3	Lost time due to exposure/injury
3.8.4	Industrial hygiene surveys
3.9	Facilities
3.9.1	Construction
3.9.2	Maintenance
3.9.3	Hydrazine facilities construction (F-16 only)
3.9.4	Hydrazine facilities maintenance (F-16 only)
3.10	Support equipment
3.11	Emergency Response (F-16 only)
3.12	Disposal
3.12.1	TWTP disposal
3.12.2	Waste collection/handling facility
3.12.3	Contractor disposal
3.12.4	Hazardous waste analyses/classifications

TASC also tried to identify the cost categories which were significant cost drivers throughout the life of the weapon system and provide recommendations as to which cost categories provided the greatest opportunities to influence Air Force material design decisions. They identified the following seven cost drivers which they felt should be included in the model for estimating costs of hazardous materials in Air Force weapon systems: personal protection, legal/environmental, medical, procurement, monitoring, disposal, and handling. These seven cost drivers account for more than 94 percent of the total cost of the hazardous materials.

The HAZMAT model is manufacturing and maintenance process driven. TASC noticed in its visits to the Air Logistics Centers and the operational sites that the use of hazardous materials in Air Force weapon systems was process driven. Examples of these processes include inspection, cleaning, washing, electroplating, painting, and stripping. Designing the model architecture as process driven allowed for modeling those situations where the process produces hazardous conditions and generates hazardous waste although hazardous materials are not used in the process.

Currently, the HAZMAT program uses a combination of analogy and parametrics methods. Table 6 shows what is currently in the HAZMAT database and what it should hold in the near future.

TABLE 6

HAZMAT SYSTEMS APPLICATIONS

Service	System	Hazardous Materials Phase		
		Acquisition	Operating &Support	Disposal
Air Force	F-15			
	F-16			
	B-1			
	C-130			
	Titan IV			
Army	Black Hawk			
	M1-A1			
Navy	Mark 50			

Complete

First & Second Stage

Transmission Only

Each system type excluding the fighter series, only has one representative database. The bombers are represented by the B-1, the carriers by the C-130, missiles by the Titan IV, and fighters by the F-15 and F-16. The data in this database is used, as well as the inputs of the user, to model twelve complicated cost algorithms to generate a new estimate. It is in this manner that HAZMAT relies heavily on the analogy and partially on the parametric equations of the cost algorithms.

Implementation.

The next section which discusses Phase II is derived from the Hazardous Materials Life Cycle Estimator User's

<u>Guide</u> written by TASC. The estimator facilitates doing cost trade-off studies and analyses between currently used hazardous materials and other, less hazardous or nonhazardous materials. The objective is to reduce the kinds and amounts of hazardous materials used in weapon systems and their associated development, production, maintenance, and decommissioning processes.

To generate an estimate, the user has an initial selection of weapon system, type, subsystem, phase, and process. After the process is identified, the materials to be used in the process can be selected. This can be done by way of pre-programmed lists for known substances or by user entry of custom substances into the estimate database. The user can enter up to three groups of chemicals with a maximum of fifteen substances each for the cost trade-off analysis. The estimator computes costs for the following cost elements: procurement, transportation, personal protection, management, training, handling, potential legal/environmental liability, medical, facilities, support equipment, emergency response, and disposal. Figure 2 presents a flowchart of how the program works.

The HAZMAT user may choose to model the cost of hazardous materials for one system for one year or the cost for hazardous materials throughout an entire phase in the life of the subsystem. Phase choices are: acquisition, operating and support, and decommissioning. TASC has
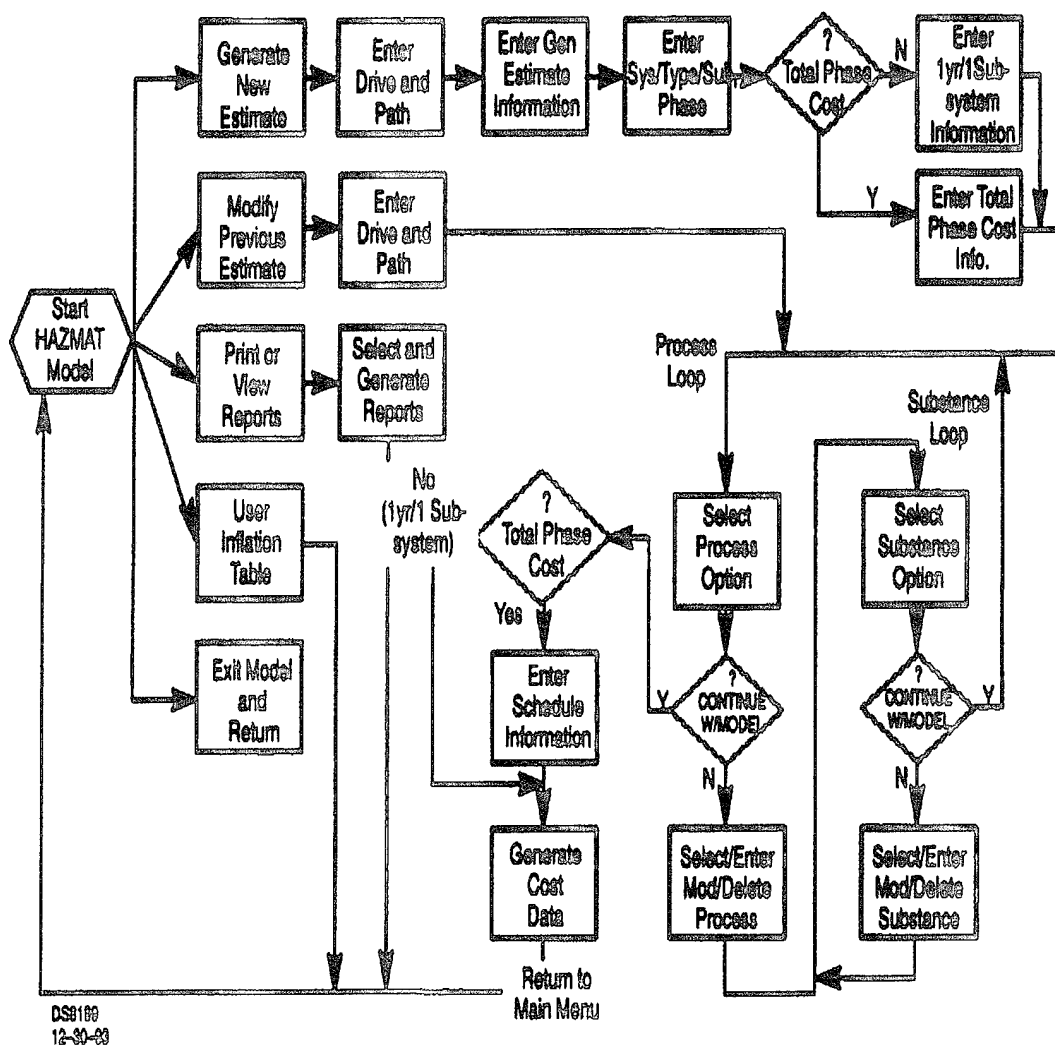
Figure A-1 HAZMAT Flow Diagram

FIGURE 2 HAZMAT Flow Diagram

modeled the surface area factor so that the database can be used to model systems that are not included.

According to the User's Guide:

> The parameter Surface Area (in square feet) Subsystem
> Type Total allows the user to extrapolate from systems
> currently in the database to systems that are not in
> the database. For example, the F-16 with a surface
> area of 1500 square feet, is currently in the database.
> If the user desires to find the cost of hazardous
> materials for a fighter twice the size of the F-16,
> then 3000 is entered for this parameter and, where
> appropriate, costs are linearly increased to account
> for the increased size. (8:3-11)

Understanding the language used in the model is key to
the success of the user. The following cost element
definitions will assist the user in understanding the
requirements for the HAZMAT model (8: B-2).

> *Procurement* includes the actual purchase price of the
> hazardous materials plus the cost of transportation to
> the site of use, whether it be a manufacturing site,
> depot or operating location.

> *Transportation* captures the cost of transporting the
> hazardous materials from one location to another at the
> point of use.

> *Personal Protection* consists of three sub-elements: the
> cost of the personal protection equipment including
> maintenance and support, the cost of inefficiency as a
> result of wearing the equipment, and the cost of
> dispensing the equipment.

> *Management* includes those functions necessary to
> maintain oversight of the hazardous materials at the
> locations where they are use.

> *Training* accounts for the cost of training personnel in
> the proper handling, storage, and use of hazardous
> materials, as well as, training in the proper use of
> personal protection equipment.

> *Handling* is attributed to the cost of subdividing,
> labeling, and distributing the materials, and the cost

of lost productivity due to the controls placed on the hazardous materials and their distribution.

Potential covers potential liability for violations Legal/Environmental of twelve Federal environment acts or Liability laws. It also has special provision for violations of the Clean Air Act. (Potential legal/environmental liability is directly related to the amount of hazardous waste disposed.)

Medical consists of four subelements: occupational physical examinations, including lost time while the physical is administered; medical surveillance; cost associated with lost time due to illness/injury as a result of hazardous materials; and industrial hygiene surveys.

Facilities accounts for the cost of constructing and maintaining facilities especially for hazardous materials and hazardous waste.

Support Equipment covers the cost of special equipment to handle hazardous materials and hazardous waste, including sensing devices and laboratory equipment.

Emergency Response accounts for the cost of emergency personnel and equipment in responding to hazardous materials and hazardous waste accidents, incidents and spills.

Disposal encompasses the cost to operate an Industrial Waste Treatment Plant (IWTP), where applicable; waste collection and handling; contractor disposal; and hazardous waste analysis and classification.

HAZMAT Cost Algorithms

The basic cost calculation for the estimator is cost per subsystem per year. For each group, the cost for each substance is determined for all twelve algorithms. Individual substance costs are then added to get the group cost (8:Appendix H).

PROCUREMENT:
COST=SURFACE_RATIO*QTY_SUBSTANCE_USED*UNIT_COST   (1)
where
SURFACE_RATIO=SURFACE_AREA_EST/SURFACE_AREA_CORE   (2)

TRANSPORTATION:
COST=SURFACE_RATIO*QTY_SUBSTANCE_USED_LBS*
     TRANS_COST_LB   (3)

HANDLING:
COST=SURFACE_RATIO*QTY_SUBSTANCE_USED_LBS*
     COST_HANDLING_LBS   (4)

MANAGEMENT:
COST=SURFACE_RATIO*QTY_SUBSTANCE_USED_LBS*
     MANAGE_COST_PER_LB   (5)

TRAINING:
(in acquisition phase)
COST=(NUMBER_OF_WORKERS_IN_PROCESS_REQUIRING_TRAINING*
     COST_PER_WORKER_FOR_TRAINING)/AVG_NUMBER_OF_
     SUBSYSTEMS_PRODUCED_PER_YEAR   (6)
(in operating and support phase at the depot)
COST=(NUMBER_OF_WORKERS_IN_PROCESS_REQUIRING_TRAINING*
     COST_PER_WORKER_FOR_TRAINING)/AVG_NUMBER_OF_
     SUBSYSTEMS_PER_YEAR_DEPOT   (7)
(in operating and support phase at the operating
location)
COST=(NUMBER_OF_WORKERS_IN_PROCESS_REQUIRING_TRAINING*
     COST_PER_WORKER_FOR_TRAINING)/AVG_NUMBER_OF_
     SUBSYSTEMS_PER_YEAR_OPERATING-LOCATION   (8)
(in the decommissioning phase)
COST=(NUMBER_OF_WORKERS_IN_PROCESS_REQUIRING_TRAINING*
     COST_PER_WORKER_FOR_TRAINING)/AVG_NUMBER_OF_
     SUBSYSTEMS_DECOM_PER_YEAR   (9)

PERSONAL PROTECTION:
COST=EQUIP_COST+WORK_LOSS_COST+DT_COST   (10)

POTENTIAL LEGAL/ENVIRONMENTAL LIABILITY:
COST=COST1+COST2   (11)
where
COST1=SURFACE_RATIO*QTY_SUBSTANCE_USED_LBS*CTRDISP_
     PERCENT*CTRDISP_RATIO*CTR_LEG_ENV_COST_LB   (12)
COST2=SURFACE_RATIO*QTY_SUBSTANCE_USED_LBS*AIR_ENV_
     PERCENT*AIR_LEG_ENV_COST_LB   (13)

MEDICAL:
COST=EXAM_COST+SURV_COST+INJURY_COST+IH_COST   (14)
FACILITIES:
COST=(SURFACE_RATIO*QTY_SUBSTANCE_USED_LBS*FACILITY_
        COST_LB)(1+FACILITY_MAINT_FACTOR)   (15)

SUPPORT EQUIPMENT:
COST=SURFACE_RATIO*QTY_SUBSTANCE_USED_LBS*COST_SUPPORT_
        EQUIPMENT_LB   (16)

EMERGENCY_RESPONSE:
COST=SURFACE_RATIO*QTY_SUBSTANCE_USED_LBS*COST_
        EMERGENCY_RESPONSE_LB   (17)

DISPOSAL:
COST=IWTP_COST+CTRDISP_COST+CLASS_ANAL_COST+RECYCLE_
        COST+AIR_ENV_COST   (18)

Validation.

The contract for validation of the HAZMAT model was
awarded to TASC, the original developer of the model. The
Air Force usually requires an independent assessment of
purchased models. Although TASC was able to use the F-15 to
validate the model, we do not feel that the model has been
adequately proven.

It is reasonable to expect TASC to be able to repeat
their original process with a new aircraft and duplicate
their results. The question remains whether or not the
average user in the field can gather enough information to
use the HAZMAT model and generate a good estimate. TASC
claims that they have verified that the model generates
costs which have less than a 15 percent variance from
actuals. The problem does not lie in the variance; the
problem lies in what TASC refers to as actuals.

Until recently, the Air Force made no real effort to track the cost associated with hazardous materials and pollution prevention. When TASC tried to gather their cost data to generate a database for this program, they had to assimilate cost information from the depots, the prime contractors, and the users. It is questionable whether another team of experts would generate the same cost data from these sources that TASC did due to the fact that TASC had to extrapolate much of the data from files that did not specify what the specific costs associated with hazardous materials were.

Data in the HAZMAT program is secondary data: "derived from the original or primary data. (6)." When TASC collected their data for the HAZMAT model in 1991, the Air Force had not yet implemented a program to track the costs associated with hazardous materials; therefore TASC had to extract the data from normal financial files that were not intended to solely capture the costs associated with hazardous materials. "The prime contractors, ALC's, and operating locations had sufficient data, but quite often it was in a form that required extensive analysis to make it usable (20:47)." Although TASC went to the original source to collect their data, we must consider their data secondary because it was derived through averages and formulas to extract the information.

Despite the fact that this model has not been adequately validated, we are going to use its database to formulate our model due to time constraints. It is the only database of its kind and we feel that we can formulate an adequate model based on this data.

Conclusion

Our literature review indicates that the Air Force needs a LCCE for HM usage in major systems in order to support its objectives of eliminating or mitigating the impact of HM usage over the life cycle of a system. We have seen that HM can command a large percentage of the total cost of a system over its life time. Also, as in the case of the EPU in the F-16, we see that by looking for alternatives to HM, we may be able to reduce future costs by eliminating special training, protective clothing and medical requirements. The development and the implementation of the HAZMAT model were explored. This thesis will generate cost estimating relationships that will allow the HAZMAT model to be re-configured to generate LCC estimates with fewer inputs. The next chapter will discuss the research methodology that will be used for improving the HAZMAT model.

III. Methodology

Overview

The purpose of this chapter is to present the methodology for simplifying the HAZMAT program. The structure and development of the program were explored in the previous chapter. It is important to remember that the primary purpose of this research effort is to refine the HAZMAT model so that environmental analysts and program managers can obtain reasonable LCC estimates in the early phases of the acquisition process without knowing site-specific and operation-specific information. The current structure of the program and the data that is currently included in the HAZMAT database indicated what type of cost estimating method should be used. Once the estimating method was identified, a method for evaluating the results was developed. This final phase of the research indicates how well the transformation maintained the validity of the database.

Review HAZMAT

The first step in this project was to thoroughly review the HAZMAT model. The review of all literature documenting the HAZMAT model was presented in Chapter II. The internal workings of the model, the organization and structure of the database, and the logic of the model had to be thoroughly analyzed before we could continue.

Expert Opinion

The second step was to conduct informal interviews with the developers of the HAZMAT model and environmental analysts in program offices in AFMC\ASC to assess the needs of the acquisition community. We were able to gain insight from the analysts at TASC on how they gathered their data and assimilated their cost algorithms. The interviews were conducted in person in informal settings and allowed to develop as open-ended group discussions. This format of interviews allowed us to maximize the amount of guidance and information we could get from TASC.

One of the topics that was covered in these interviews was the development of the cost drivers by TASC. This discussion allowed us to evaluate the primary cost drivers in their model and determine if and how they would be included in our model.

The environmental analysts provided information on why potential users had not utilized the capabilities of the HAZMAT model. They provided us with potential cost drivers for a model that will be used during the conceptualization phase of development. It is essential that a cost driver be knowable. This means that the user must have a value associated with the cost driver when he is preparing to run the model. The environmental analysts told us what factors they have access to during this phase.

Development of Cost Algorithms

In order to determine what type of cost algorithms we would use, we reviewed the different types of cost estimating methods. The next step was to determine whether our model will be process or substance driven. The final step was to generate the CER and define the cost drivers.

Cost Estimating Methods.

A cost estimate is a forecast of a future cost based on a logical extrapolation of available historical data. The choice of estimating method depends on the level of program definition, level of detail required, availability of data, and time constraints (6:3-21). The three primary methods considered for this research effort were the parametric method, the analogy method, and the grass roots method. The Cost Estimating Handbook provided the following information on these techniques.

The parametric method involves collecting relevant historical data at an aggregate level of detail and relating it to the area to be estimated through the use of mathematical techniques. This method usually requires less detail than other methods because it captures the cost at very high levels. It is normally used during the early stages of a program, when there is limited program and technical definition. Parametric analysis normally utilizes one or more cost estimating relationships. Parametric analysis can also be found in the form of factors or ratios

used to capture costs. Although regression is one of the most common types of parametric analysis, parametrics are not limited to regression techniques. A parametric can be any mathematical model of a cost relationship.

The advantage of using parametric techniques is that they capture major portions of an estimate in a limited amount of time and with limited program definition. CERs reflect the impacts of system growth, schedule changes, and engineering changes because they are based on actual program cost history. The limitations of parametrics include some key principles relevant to the analysis of hazardous materials. When the parametric used captures cost at a very high level, it does not provide a low-level of visibility into discrete areas. As a result, subtle changes in design cannot be reflected in the estimate. Another limitation is that the individual pieces of the estimate may not be separable.

The analogy method uses actual costs of similar existing or past programs, and adjusts for complexity, technical, or physical differences to derive the new system estimate. This method is typically used early in a program cycle when there is insufficient actual cost data to use a basis for a detailed approach; but there is a sufficient amount of program and technical definition based on study results and test data. A detailed engineering assessment is required to ensure the best analogy has been selected and

proper adjustments are made. Breaking the estimate down into a low-level of detail enhances the credibility of the estimate as separate analogies can be chosen for each component.

Analogy estimating is an excellent choice when the new system is primarily a new combination of existing subsystems, equipment, or components for which recent and complete historical cost data are available. In the case of hazardous materials, when we are trying to estimate the costs of a hazardous material that has been used in a prior system, an analogy can be very powerful. Analogy cost estimates are used by breaking the new system down into components that can be compared to similar existing components. However, when looking at new materials with unknown effects, it will be very hard to generate any kind of cost estimate. We can look to our commercial counterparts for data on materials that we have never incorporated into our systems but the commercial sector is using.

The primary advantage to the analogy method is that we only need one system in our database upon which to compute our estimate. There are two main limitations to the analogy method. It requires detailed program and technical definition of both the analogous system as well as the system being estimated. Engineering judgment becomes the basis of the methodology. Although the engineering judgment is one of the benefits of this method, it is also one of its

limitations. Sound engineering judgment is essential to the

success of this method.

Steps of the analogy method are as follows:

- Determine estimate needs and ground rules
- Define the system
- Plan breakout of system for analogy estimating
- Assess data availability
- Describe the new system components
- Collect prior system component design and performance data
- Collect prior system component cost data
- Process/normalize prior system component cost data
- Develop factors based on prior system costs
- Develop the new system component cost improvement slope values
- Review ratios and factors
- Obtain complexity factor values
- Obtain miniaturization factor values
- Obtain productivity improvement factor values
- Apply factors to obtain new system costs
- Develop new system PME cost estimates
- Develop other new system costs with factors
- Develop total program costs
- Review the estimate
- Document the estimate

The grass roots method is also known as the engineering

build-up or detailed estimate method. This method provides

the user with an estimate performed at the functional level

of the WBS. This method is normally utilized during the

production phase of the program cycle when the configuration

has stabilized, test results are available, test results are

available, and Full Scale Development and production cost

actuals have accrued. The main hypothesis of the grass

roots method is that future costs for a system can be

predicted with a great deal of accuracy from historical costs of that system. The primary limitation of this approach is that it is very time-consuming and there is a need for detailed cost data.

This research effort used the current database in HAZMAT to continue with an analogy. The database had the following setup. All of the system level parameter values are maintained in files rather than being hard-coded (8:A-2). There are two separate sets of files: the permanent file and the estimate files. Although TASC identified seven cost drivers that they felt were significant in hazardous materials cost estimating, we believe that the majority of these costs can be captured by surface area and the number of subsystems purchased. This allows the current database to be simplified and the inputs required to generate an estimate are reduced to only two. We are able to do this by using the database provided in the HAZMAT model and continuing the HAZMAT analogy. After talking with several experts in different Special Project Offices, we realized that the only data available very early in a program was a general idea of how large the system would be and how many systems would be produced. We assume that an estimate for a new system will be analogous to one of the core systems in the HAZMAT database. Then our model figures what percentage larger or smaller the new system will be and increases or decreases the HAZMAT core estimate by that much. An analyst can do cost tradeoffs early in the

estimate by removing or adding substances used in the core estimate.

Process vs. Substance Driven.

The current system is process driven. A process is defined as a function performed on a system where one or more substances may be used. Process driven means that the estimate is computed by summing the 11 cost elements for each process used on a system. In the earlier phases of the acquisition cycle, it would be more efficient to have a substance driven estimate. In this case, the 11 cost elements for each substance are summed to figure a LCC for each substance used on the system. Then the substance LCCs are summed to get the total LCC of the system.

The primary interest during these early phases is for trade-off analyses between substances. By totaling the amout of each substance used on a Core system and multiplying it by the costs associated with each cost element, we generated a total cost per substance used in a system. The next step was summing the costs associated with all the substances used in a system to generate a total cost of hazardous materials in a system. The user will be able to add or delete substances from this process in order to measure their effects on the system cost.

The Cost Estimating Relationship.

In developing our cost algorithms, one of our foremost goals was to limit the number of cost drivers. The requirements for choosing the factors included the following limitations: (1) data availability during the conceptualization phase; (2) cost drivers must be already included in the database; (3) the expert must agree that this factor will drive the cost of the hazardous material; (4) and limit the total number of inputs to keep the model manageable.

The CER for the model developed by this research effort follows:

$$\text{COST} = \text{\#SUBSYSTEMS} \times (\text{SURFACE AREA} / \text{CORE \# SURFACE AREA})$$
$$\times (\text{COST OF USING SUBSTANCES} / \text{PER SYSTEM} /$$
$$\text{PER YEAR}) \qquad\qquad (19)$$

Modify the HAZMAT Database

The next step was modification of the HAZMAT database to accommodate our cost algorithms. We loaded the database into a Microsoft Excel spreadsheet in order to format the data into the format required for our model to operate.

Model Validation

The final step was validation of the model. Using six different subsystem and phase combinations, we estimated the costs of hazardous materials for an entire subsystem and

compared the results with the estimate generated with the default values in HAZMAT. We used percentage difference as a measure of validity. The percentage difference between the two estimates was calculated as follows:

$$\% \text{ Difference} = (\text{HAZMAT Estimate} - \text{Our Estimate}) / \text{HAZMAT Estimate} \qquad (20)$$

Our model can be no more accurate than the current HAZMAT model due to the fact that our entire model is based on the HAZMAT database.

Conclusion

This chapter has presented the methodology that will be used to accomplish the goal of this research effort. After analyzing the HAZMAT model as it currently operates, it was obvious that the best approach was to use the database already developed and continue with an analogy approach. The validation of the newly developed model determines if the model generates estimates that are accurate enough to be used for forecasting costing during the early phases of the acquisition life cycle. Chapter IV will present the results of the data transformations and a model of how the transformation occurred.

IV. Analysis and Results

Overview

This chapter will describe how we manipulated the database supplied with the HAZMAT program to obtain a substance driven estimate of LCC hazardous materials used in a major weapon system. We will also describe how we used the HAZMAT program to generate a point estimate.

HAZMAT Estimate

An estimate for the costs of hazardous materials associated with a core system and its phase of development was calculated using the HAZMAT model for the sake of comparison. We chose to analyze the Fighter aircraft airframe during the acquisition, operating and support, and disposal phases. For each phase, all possible processes associated with the phase were chosen with the use of all possible substances for that process (HAZMAT limited the total number of substances to 15 for each process) and the default values for the substances. The HAZMAT program uses default values that they discovered in their origination of the database.

Once an estimate was generated for each process, the costs were summed to generate an estimate for all processes used during that phase for the fighter airframe. This

45

process of extracting an estimate from HAZMAT was not difficult although it was time consuming. This estimate was used to validate the cost estimate generated by the new model developed in this thesis.

Our Algorithm

The HAZMAT program contains seven permanent database files: Core, Phase/Process, Substance, Personal Protection Equipment, Physical Exams, Inflation Table, and Join Relationship. The files that we must manipulate to perform our substance-based estimate are Substance, Phase/Process, Personal Protection Equipment and Join Relationship. These files are very large when placed within a spreadsheet. The Join Relationship file for Core 1 alone requires a spreadsheet with more than 5000 rows and 11 columns in each row. The other three files (Core, Physical Exams and Inflation Table) are very small. Any data necessary for our estimate can be looked up and placed into the spreadsheet manually.

A system administrator program was provided to us by TASC to give us access to the data files. This program prints the data bases to text files. These text files then have to be parsed into the spreadsheet. Parsing is dividing a line of text into individual pieces of information, each placed in its own block in the spreadsheet. Before we had

access to Excel 5, this operation required us to write a macro which would step through each line of the text file and parse it into the spreadsheet. A macro is a programming function which allows you to record sequential keystrokes when operating with a database. If these keystrokes have to be performed over and over, the macro can perform these steps with one keystroke. These macros can be place in iterative loops which will perform the operation a set number of times. With the size of some of the text files, this operation could take up to 45 minutes to run through the 5000 iterations required. Excel 5 has an automatic parsing function built in which will convert the text file to a spreadsheet as it is opened.

The system administrator had several bugs which kept the program from printing out certain key variables in two files. This item will be discussed later since it explains some of the difference between the estimate generated by our algorithm and the estimate which HAZMAT generated.

Once the text files were parsed into the spreadsheet we used database functions defined by Excel to extract the information necessary to perform the estimate. Once again, we defined macros and used iteration to complete these tasks as quickly as possible. The overall method was to perform the calculations for each process as defined by HAZMAT. Then, because we knew which substances were used in that

process, we apportioned an equal part of the total cost of that process to each substance used within the process. Totaling the portions from each process in which a substance was used gave us the total LCC for a particular substance.

The total cost for a particular phase and core is summarized on one spreadsheet. (See attachments of our algorithms spreadsheet) The name of the core and the phase is at the top of the spreadsheet for each estimate. To the left is the estimate generated by our algorithm and the estimate generated by HAZMAT. In between the two estimates is the percentage difference between the two estimates. The total cost is broken down into 11 elements across the top. These elements are the same cost elements used by HAZMAT. Along the side of the database are the names of each substance used in this core and phase along with their LCC cost broken down into each element. The only required inputs for generating an estimate for a new system would be surface area and number of systems built. Our algorithm would then give you the cost per system, per year for the phase that is being estimated (i.e. acquisition, operation and support, disposal).

Once the first algorithm was completed, a sequence of steps was generated for obtaining the necessary data for a new core and phase. These steps are as follows:

1.) Make a template of the previous cost spreadsheet.

2.) Extract a list of unique processes for the phase and core of the new estimate (i.e. Core 1 Disposal).

3.) Using the list of unique processes, extract the list of unique chemicals for each process from the Join Relationship database.

4.) Using the list of unique substances, extract substance data for each substance from the Substance Database.

5.) Using the data from above, total the amount used for each substance.

6.) To obtain Procurement Cost, multiply the total amount used by cost per pound for each substance.

7.) To obtain Management Cost, multiply the total amount used by Management Cost Per Pound for each substance.

8.) To obtain Handling Cost, multiply the total amount used by Handling Cost Per Pound for each substance.

9.) To obtain Facilities Cost, multiply the total amount used by Facilities Cost Per Pound for each substance.

10.) To obtain Support Equipment Cost, multiply the total amount used by Support Equipment Cost Per Pound for each substance.

11.) To obtain Emergency Response Cost, multiply the total amount used by Emergency Response Cost Per Pound for each substance.

12.) To obtain Transportation Cost, multiply the total amount used by Transportation Cost Per Pound for each substance.

13.) To obtain Legal Cost, use the HAZMAT equations which will give you the total cost for each process. For each process, divide the cost by the number of chemicals which are used in the process. Apportion that cost to each chemical used within the process. Sum the apportionments from each process for each chemical. This will be the total Legal Cost for each substance.

14.) To obtain Training Cost, use the HAZMAT equations which will give you the total cost for each process. For each process, divide the cost by the number of chemicals which are used in the process. Apportion that cost to each chemical used within the process. Sum the apportionments from each process for each chemical. This will be the total Training Cost for each substance.

15.) To obtain Disposal Cost, use the HAZMAT equations which will give you the total cost for each process. For each process, divide the cost by the number of chemicals which are used in the process. Apportion that cost to each chemical used within the process. Sum the apportionments from each process for each chemical. This will be the total Disposal Cost for each substance.

16.) To obtain Personal Protection Equipment Cost, use the HAZMAT equations which will give you the total cost for each process. With this cost element, you must total the cost of buying the equipment. Because several of the chemicals used in the process use the same equipment, you should only count unique pieces of equipment. In other words, if two chemicals require the use of safety glasses, you only count those safety glasses once for the process. The biggest cost driver for the entire estimate is Work Loss due to constraints of wearing personal protection equipment. Once again, since there are several chemicals used in each process, you must total the work loss for each chemical, then choose the most expensive work loss cost as the cost for the entire process. For each process, divide the cost by the number of chemicals which are used in the process. Apportion that cost to each chemical used within the process. Sum the apportionments from each process for each chemical. This will be the total Personal Protection Equipment Cost for each substance.

We performed these steps for three different estimates: Aircraft-Fighter-Airframe-Acquisition, Aircraft-Fighter-Airframe-Operations and Support, and Aircraft-Fighter-Airframe-Disposal. The results for the Aircraft-Fighter-Airframe-Operations and Support estimate are inconclusive. This is due to an error in the HAZMAT program which only

prints half of the processes used in the estimate report.

Therefore, we have no way of checking the results of our

algorithm.

The results for the other two estimates are presented

in Table 7:

TABLE 7

COMPARISON OF HAZMAT TO SUBSTANCE-DRIVEN ESTIMATE

ESTIMATE TITLE	HAZMAT	OURS	% DIFFERENCE
Aircraft-Fighter-Airframe-Acquisition	$10,302,100	$9,895,291	3.95%
Aircraft-Fighter-Airframe-Disposal	$7,362,920	$7,109,994	3.44%

The percentage difference between the two estimates was

calculated as follows:

% Difference = (HAZMAT Estimate - Our Estimate) /

$$\text{HAZMAT Estimate} \qquad\qquad (20)$$

As mentioned earlier, there was a bug with the System

Administrator Program which kept us from obtaining some of

the data necessary to do a complete estimate. We believe

that this loss of data contributes to the differences

between the HAZMAT estimate and the estimate generated by

our algorithm. The missing data is in the Phase/Process and

the Substance Databases. From Phase/Process we were missing

Classification and Analysis Cost per Pound. From the

Substance database we were missing the Disposal Percentage

breakdowns. This missing data affected the Disposal Cost

Element making it lower than it should be. We confirmed

with Dr. John Long of TASC that this data was available

within the HAZMAT program, but the program bug in the system

administrator did not put the data in the exported text

files. Time constraints kept us from trying to get the data

and rerun the estimate with our algorithm.

Conclusion

This chapter has shown how a model was produced that

can effectively be used during the conceptualization phase

of a system. The results of the newly formed substance

driven model compared very well with the results of the

HAZMAT model. The process used to extract the database and

set up the spreadsheet for the fighter airframe could be

replicated for any other set of core data in the HAZMAT

model. Chapter V will present the recommendations for

future use of this model and a summary of this research.

V. Summary and Recommendations

Overview

Chapter IV described the process used to develop a substance driven model that can be used during Phase I of development to estimate the costs associated with using hazardous materials in a weapon system. That chapter also presented an analysis of the new model's results compared with the HAZMAT model's estimate. Chapter V offers a summary of this research effort, recommendations based on the findings of this research, and recommendations for future areas of study. The recommendations are the most important part of this research and represent a direction for the Air Force to pursue in further research for the life cycle costs of hazardous materials in major weapon systems.

Summary

Chapter I presented an overview of the research objectives and issues that this paper would present. The purpose of our research was to modify the HAZMAT model developed by TASC so that it could be more effectively used by System Program Offices to generate cost estimates for hazardous materials during the conceptualization and design phases of weapon system development. We chose the HAZMAT model because it had the only organized database for

hazardous materials costs during the various life cycle

phases of a weapon system. HAZMAT gave its user the

capability to do tradeoff analyses of various substances

that could be used in different processes associated with a

weapon system. The program did not provide the user an easy

capability of generating a total life cycle cost estimate

associated with all hazardous materials used in a weapon

system.

Using the HAZMAT database and the research that TASC

had compiled on hazardous materials, we were able to

generate a spreadsheet which allows the user to generate a

system cost. Our model was designed for the fighter

aircraft airframe during the acquisition and disposal

stages. However, our methodology could easily be used to

develop similar models and spreadsheets for any type of

system combination contained in the HAZMAT database.

The estimates generated by our model are dependent on

the validity of the cost figures in the HAZMAT database.

However, the lack of use of the HAZMAT model by potential

users in the field reflects the user's lack of understanding

of how to use the HAZMAT model and their lack of knowledge

of the capabilities of HAZMAT. The model that we have

generated is much more user-friendly and understandable to

the average analyst in the field. It also provides the

analyst with a figure which will be very useful to him in

justifying the elimination and control of hazardous
materials in weapon system development.

Investigative Questions

These are the investigative questions posed in Chapter
1 along with the answers we discovered:

(1) What information is available in the database maintained
by HAZMAT? The data base contains all known substances and
processes used by a core system throughout it's life cycle.
It also contains all data necessary to compute the costs
associated with those substances and processes. This data
has not been independently validated, therefore, our results
can only be as good as the data. (For more detail, see
Chapter 2, pages 34-35)

(2) What information do environmental analysts and program
managers have about the weapon system before the design is
specified? Through discussion with experts in several
Special Project Offices we found that analysts would only
have a general idea of how large a system would be and how
many would be produced. (For more detail see Chapter 3, page
50)

(3) What are the major cost drivers for hazardous materials
usage? The major cost driver as evidenced within our model
shows that the costs associated with Personal Protection
Equipment (PPE) and more specifically, work performance lost
due to using PPE can account for over 90% of the hazardous

material LCC. (See our model's spreadsheets in the appendix.)

(4) Do the available independent variables adequately capture the costs associated with hazardous materials usage? Since the HAZMAT model and database have never been independently validated, we cannot answer this question for sure. TASC's validation information says that the model is within 15% of actual costs.

Recommendations for Future Use

The importance of the development of this model goes much further than just the two cost model spreadsheets that we were able to develop. The most important part of this paper is the discovery that the environmental analyst in the field does not feel that he has the adequate tools to calculate a life cycle costs. The growing importance of planning for hazardous materials requires that an analyst has this capability. Although the original HAZMAT model was developed to give an analyst the capability to do tradeoff analyses, it has not fulfilled all of the user's needs. In its current form, the potential user has little use for the HAZMAT model.

Future efforts to refine this model and develop new life cycle costs models for hazardous materials should focus on a substance-driven approach that provides the user with a simple way to calculate the system costs. Although the

processes are very important to the weapon system user, the engineer and developer of the weapon system design is much more concerned with the use of particular hazardous materials throughout the weapon system life. Therefore, we recommend that the best life cycle cost model for early use during weapon system development should be substance-driven.

Recommendations for Future Study

A good thesis effort in the future would be to try to validate the original HAZMAT cost data. We have found that no program in the Air Force has been able to use the HAZMAT model in their efforts to estimate the life cycle costs of hazardous materials. Many people in the field do not have confidence in the HAZMAT model because they feel that it was never adequately validated. The validation for the HAZMAT model was performed by TASC, the developer of the model. An adequate validation of this model is mandatory for its future success.

Appendix A: ACRONYMS

LCC   Life Cycle Costs

HM   Hazardous Material

HAZMAT   Hazardous Materials Life Cycle Cost Estimator

CER   Cost Estimating Relationship

RDT&E   Research, Development, Test, and Evaluation

LCCE   Life Cycle Cost Estimator

RCRA   Resource Conservation and Recovery Act

CAA   Clean Air Act

PEA   Program Environmental Assessment

PPE   Personal Protection Equipment

DoD   Department of Defense

AFMC   Air Force Material Command

PPP   Pollution Prevention Program

AMHM   Acquisition Management of Hazardous Materials

EPU   Emergency Power Unit

LSAR   Logistics Support Analysis Record

EPA   Environmental Protection Agency

DOE   Department of Energy

Appendix B: Substance-Driven Model Spreadsheet

	# of	1 Surface	1500			
Required Inputs						
Total Point Estimate		TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
$9,895,291		$56,469	$114	$3,660	$8,397	$146,88
3.95%						#produc
$10,302,100						
Substance Name	Substan	Procure	Transportat	Handlin	Manage	Training
DRILLING FLUID	44535	169.597	0.04296	1.38417	3.17560	3690
WAYCOAT PF THINNER	63419	0.56798	0.001265	0.04075	0.09350	180
ARGON GAS	100187	18.9979	3.06419	98.7282	226.504	540
LACQUER	168755	1.39689	0.04233	1.36387	3.12903	3510
WAYCOAT SC-180	532732	2.63784	0.009475	0.30528	0.70039	180
SEALANT	541835	2577.74	3.740205	120.509	276.475	5850
ANTICORROSIVE	625866	4.71276	0.022745	0.73284	1.68131	3600
XYLENE	688867	180.482	0.061915	1.99490	4.57675	540
NITRIC ACID	148715	527.561	3.03196	97.6897	224.122	13320
PAINT, THIN, LACQUER	160578	1121.30	11.37225	366.413	840.636	4500
ACETONE	184479	3271.62	6.19156	199.492	457.680	450
POTASSIUM DICHROMATE	222967	3.80096	0.01706	0.54967	1.26107	1260
METHYL ALCOHOL	224835	6.17391	0.00379	0.12211	0.28015	360
SULFURIC ACID	227184	80.0536	0.42267	13.6184	31.2437	6030
TRIETHANOLAMINE	234204	55.4587	1.200405	38.6770	88.7339	1620
COLLOIDAL GRAPHITE	235558	56.8291	0.221125	7.12464	16.3455	540
HYDROFLUORIC ACID	236567	6893.98	1.21557	39.1656	89.8549	8910
NAPTHA	238811	17680.0	7.5815	244.275	560.424	450
FERRIC CHLORIDE	241116	3.62378	0.01453	0.46815	1.07405	180
FINGERPRINT REMOVER	252830	4.68564	0.00316	0.10181	0.23358	2340
SODIUM DICHROMATE	262856	14.2466	0.073285	2.36124	5.41722	3960
OXALIC ACID, DIHYDRATE	264393	3.72898	0.07834	2.52411	5.79089	180
STODDARD SOLVENT	264577	11390.5	3.475485	111.980	256.907	630
PERCHLOROETHYLENE	275812	605.800	3.98029	128.244	294.223	810
SODIUM CYANIDE	281203	4.85767	0.01769	0.56997	1.30764	5580
METHYL ETHYL KETONE	281278	1868.00	18.10083	583.208	1338.01	5760
CADMIUM OXIDE	281880	37.0144	0.003155	0.10165	0.23321	5580
ISOPROPYL ALCOHOL	286543	12.5951	0.101085	3.25695	7.47220	180
CUTTING FLUID	450693	9.17105	0.12004	3.86768	8.87335	3690
PAINT, ENAMEL, ALKY, GLOSS	527319	1346.57	3.538035	113.995	261.531	4500
AMMONIUM BIFLOURIDE	584379	119.909	2.081755	67.0741	153.883	6840
PAINT, PRIM, AEROSOL, GRAY	616918	378.861	13.064185	420.928	965.704	5850
TRICHLOROETHANE	664038	2450.50	11.19977	360.856	827.886	12150
FREON TF	763131	1104.37	5.812485	187.278	429.658	450
CADMIUM	975069	4.82467	0.01895	0.61056	1.40078	5580
ISOPROPYL ALCOHOL	983855	936.264	11.119535	358.271	821.956	450
SODIUM HYDROXIDE	985709	145.200	1.27369	41.0382	94.1511	9270
METHYLENE CHLORIDE	998248	71.5904	0.00632	0.20363	0.46717	360
CHROMIC ACID FLAKES	101198	19.5525	0.00158	0.05090	0.11679	1350

Substance Name	Substan	Procure	Transportat	Handlin	Manage	Training
POLYALKYLENE GLYCOL	107497	29.2179	0.005055	0.16287	0.37366	360
SURFACTANT	114941	25.4873	0.001895	0.06105	0.14007	450
CHROMIC ACID	124521	2913.39	1.20988	38.9823	89.4343	14310
BORON NITRIDE	131151	316.217	0.0537	1.73021	3.96950	540

Required Inputs

Total Point Estimate	TOTAL	TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
$9,895,291	$9,561,606	$3	$117,11	$0	$0	$0
3.95%	#produced/		#produc			
$10,302,100						

Substance Name	Personal	Legal	Medical	Facilitie	Support	Emerge
DRILLING FLUID	196063.33	0.00064	8537.63	0	0	0
WAYCOAT PF THINNER	24654.4266	0.00004	8537.63	0	0	0
ARGON GAS	0	0.04596	1462.82	0	0	0
LACQUER	82031.95	0.00007	8133.36	0	0	0
WAYCOAT SC-180	24654.4266	0.00016	654.275	0	0	0
SEALANT	328102.45	0.00673	13638.9	0	0	0
ANTICORROSIVE	298784.53	0.00034	8585.5	0	0	0
XYLENE	42832.52	0.00199	1462.82	0	0	0
NITRIC ACID	536532.881	0.05336	31916.3	0	0	0
PAINT, THIN, LACQUER	646628	0.36846	10356.8	0	0	0
ACETONE	20909.5312	0.19936	1260.68	0	0	0
POTASSIUM DICHROMATE	159213.15	0.00030	3079.92	0	0	0
METHYL ALCOHOL	0	0.00012	1058.55	0	0	0
SULFURIC ACID	344598.025	0.00743	14543.2	0	0	0
TRIETHANOLAMINE	171367.22	0.02280	3888.47	0	0	0
COLLOIDAL GRAPHITE	336373.873	0.00380	1462.82	0	0	0
HYDROFLUORIC ACID	0	0.02139	19596.6	0	0	0
NAPTHA	20909.5312	0.24412	1260.68	0	0	0
FERRIC CHLORIDE	24654.4266	0.00025	654.275	0	0	0
FINGERPRINT REMOVER	139571.38	0.00004	5505.57	0	0	0
SODIUM DICHROMATE	174077.2	0.00128	0.46499	0	0	0
OXALIC ACID, DIHYDRATE	19482.15	0.00137	654.275	0	0	0
STODDARD SOLVENT	45563.9579	0.11191	1914.96	0	0	0
PERCHLOROETHYLENE	117227.025	0.12816	2069.23	0	0	0
SODIUM CYANIDE	149114.285	0.00033	13032.5	0	0	0
METHYL ETHYL KETONE	784764.556	0.58284	13686.8	0	0	0
CADMIUM OXIDE	149114.285	0.00005	13032.5	0	0	0
ISOPROPYL ALCOHOL	116892.9	0.00325	654.275	0	0	0
CUTTING FLUID	196063.33	0.00180	8537.63	0	0	0
PAINT, ENAMEL, ALKY, GLOSS	646628	0.11463	10356.8	0	0	0
AMMONIUM BIFLOURIDE	366702.287	0.03663	16112.4	0	0	0
PAINT, PRIM, AEROSOL, GRAY	328102.45	0.42327	13638.9	0	0	0
TRICHLOROETHANE	955583.481	0.36063	28038.5	0	0	0
FREON TF	20909.5312	0.09997	1260.68	0	0	0
CADMIUM	149114.285	0.00036	13032.5	0	0	0
ISOPROPYL ALCOHOL	20909.5312	0.35804	1260.68	0	0	0
SODIUM HYDROXIDE	891266.560	0.02241	22320.1	0	0	0
METHYLENE CHLORIDE	0	0.00020	1058.55	0	0	0
CHROMIC ACID FLAKES	279615.691	0.00002	3532.06	0	0	0
POLYALKYLENE GLYCOL	0	0.00016	1058.55	0	0	0
SURFACTANT	0	0.00003	1260.68	0	0	0
CHROMIC ACID	709760.798	0.02129	33639.8	0	0	0

Required Inputs	# of	1 Surface		1500		
Total Point Estimate		TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
$7,109,994		$9,655	$0	$245	$606	$0
3.44%						#produc
$7,362,920						

Substance Name	Substan	Procure	Transportat	Handlin	Manage	Training
TRICHLOROETHANE 1.1.1	74550	0.78305	0	0.00439	0.01086	0
LUBRICATING OIL	650115	6.6	0	0.287	0.71	0
EPOXY PRIMER COATING	822450	362.640	0	4.31142	10.6659	0
PHOTOGRAPHIC FIXING BATH	925054	2.22974	0	0.01908	0.04721	0
GREEN LACQUER PAINT	141295	0.05893	0	0.01191	0.02946	0
LACQUER	141295	0.27237	0	0.05011	0.12396	0
LACQUER	141295	2.8557	0	0.54639	1.35169	0
EPOXY RESIN	142791	0.01575	0	0.00143	0.00355	0
CORROSION PREVENTIVE	142928	3.036	0	0.1722	0.426	0
GREASE	145026	39.9913	0	0.91527	2.26426	0
HYDRAULIC FLUID	149743	42.4224	0	4.73745	11.7198	0
HYDRAULIC FLUID	149743	18.0564	0	0.52664	1.30285	0
REPLENISHER/DEVELOPER	165713	6.00492	0	0.02717	0.06723	0
LUBRICATING OIL	180626	16.1946	0	2.34740	5.80716	0
CLEANING COMPOUND	181759	15.535	0	0.1435	0.355	0
ADHESIVE	181776	31.8510	0	1.31339	3.24917	0
PAINT, THIN, ALIPH	181808	9.33912	0	0.43796	1.08346	0
PAINT, POLY, BLACK	181827	5.08387	0	0.13598	0.33639	0
ACETONE	184479	3272.17	0	35.5455	87.9350	0
ENGINE OIL	189672	0.77737	0	0.00129	0.00319	0
GREASE	190090	0.35533	0	0.00490	0.01214	0
FLUX, SOLDERING	220382	0.09682	0	0.01182	0.02925	0
ACETIC ACID	222263	0.5916	0	0.01148	0.0284	0
HYDRAULIC FLUID	223413	48.5922	0	2.01531	4.98562	0
AROMATIC NAPTHA	223906	0.76715	0	0.00143	0.00355	0
CORROSION PREVENTATIVE	224958	3.92325	0	0.02152	0.05325	0
CORROSION PREVENTIVE	231235	14.36	0	0.2296	0.568	0
LUBRICATING OIL	231667	59.2069	0	0.09267	0.22925	0
ENGINE OIL	235906	0.98301	0	0.00157	0.00390	0
CORROSION PREVENTIVE	244129	2.7624	0	0.06888	0.1704	0
CORROSION PREVENTIVE	244129	3.5504	0	0.02296	0.0568	0
CORROSION PREVENTIVE	244129	1.17	0	0.00574	0.0142	0
LACQUER	248283	3.34786	0	0.15299	0.37850	0
SODIUM BICARBONATE	249935	61.08	0	3.444	8.52	0
ELEC. FOR BATTERY	249935	1.392	0	0.13776	0.3408	0
PETROLATUM, TECHNICAL	250092	13.9051	0	1.74269	4.31119	0
CLEAR LACQUER	251649	0.763	0	0.01004	0.02485	0
RED LACQUER	251650	0.82824	0	0.04244	0.10500	0
BORIC ACID	264653	2.09999	0	0.16158	0.39973	0
CHLOROBENZENE	264900	0.00588	0	0.00002	0.00007	0
CORROSION PREVENTATIVE	274416	19.949	0	0.0287	0.071	0

Substance Name	Substan	Procure	Transportat	Handlin	Manage	Training
METHANOL (METHYL	275601	0.07847	0	0.00123	0.00305	0
ACETONE	281186	0.13989	0	0.00022	0.00056	0
TOLUENE	281200	0.38882	0	0.02166	0.05360	0
CORROSION PREVENTIVE	281203	7.7857	0	0.03731	0.0923	0
METHYL ETHYL KETONE	281278	1915.03	0	106.514	263.502	0
CARBON REMOVING	281304	46.3474	0	0.03349	0.08285	0
ISOPROPYL ALCOHOL	286543	47.4707	0	2.18685	5.40998	0
NAPTHA COMPASS FLUID	290005	0.432	0	0.03444	0.0852	0
PNT, AEROSOL, BLK, ENAMEL	290698	1.17555	0	0.26358	0.65206	0
PRIMER COATING	292112	27.0908	0	0.43460	1.07515	0
LUBRICATING OIL	292965	0.53599	0	0.01908	0.04721	0
SEALING KIT	297719	0.366	0	0.01722	0.0426	0
LUBRICATING OIL, GENERAL	458007	3.97379	0	0.40877	1.01125	0
STABOND HT-11 SEALENT	515223	0.66885	0	0.00430	0.01065	0
SC-840	515225	6.50312	0	0.31262	0.77340	0
CORROSION PREVENTIVE	526160	0	0	0	0	0
1,1,1-TRICHOROETHANE	551148	516.416	0	0.28344	0.70119	0
CLEANING COMPOUND	559283	0	0	0	0	0
CLEANING AND LUBRICATING	570936	8.77549	0	1.31862	3.26209	0
LACQUER	584315	1.99644	0	0.41520	1.02715	0
METHANOL	597360	0.47997	0	0.02132	0.05275	0
ENAMEL	598593	2.05527	0	0.32232	0.79740	0
CLEANING COMPOUND	611799	1.89528	0	0.18376	0.45461	0
SCALE REMOVING COMPOUND	637614	0.17795	0	0.00054	0.00134	0
ANTIFREEZE	664140	2.57752	0	0.00312	0.00773	0
ADHESIVE	664431	0.93578	0	0.07565	0.18715	0
LAYOUT DYE	664906	0.8618	0	0.03989	0.09869	0
CORROSION RESISTANT	720973	48.3064	0	0.13589	0.33618	0
YELLOW LACQUER PAINT	721974	9.56386	0	1.61460	3.99431	0
LACQUER	721975	1.29005	0	0.25359	0.62735	0
ADHESIVE	738642	1.25955	0	0.09588	0.23721	0
SEALING COMPOUND	753459	0.1614	0	0.00861	0.0213	0
LUBRICATING OIL	753466	0.05485	0	0.00143	0.00355	0
FREON TF	763131	1104.77	0	33.3759	82.5676	0
ENGINE OIL	782262	30.6078	0	2.00558	4.96155	0
LUBRICATING OIL	782267	32.8610	0	0.01119	0.02769	0
INSPECTION PENETRANT KIT	782274	37.6323	0	0.38340	0.94848	0
ALODINE COATING	823803	0.86460	0	0.03782	0.09357	0
	855616	0	0	0.01644	0.04068	0
CORTEC VCI-560	865291	0.1235	0	0.00287	0.0071	0
SILICONE COMPOUND	880761	1.29785	0	0.11253	0.27839	0
DENT FILLER	926213	1.16655	0	0.04735	0.11715	0
LUBRICATING OIL, GENERAL	932949	0.105	0	0.02152	0.05325	0
AIRCRAFT GREASE	935585	58.3494	0	0.22334	0.55252	0
HYDRAULIC FLUID	935980	0.902	0	0.12628	0.3124	0
SILICONE	941998	40.6068	0	1.52741	3.77862	0
PNT, AEROSOL, ORANGE, LAC	958814	0.82457	0	0.12074	0.29869	0

Substance Name	Substan	Procure	Transportat	Handlin	Manage	Training
LACQUER	958815	0.011	0	0.00143	0.00355	0
AIRCRAFT TURBINE LUBE OIL	985703	2.32	0	0.287	0.71	0
GREASE	985724	24.7883	0	0.35323	0.87386	0
HYDRAULIC FLUID	100977	15.1156	0	0.04132	0.10224	0
PAINT STRIPPER	102124	24.025	0	0.35875	0.8875	0
PAINT, POLY, GREEN	102342	49.9478	0	0.36420	0.90099	0
INSPECT PENETRANT	102457	8.0313	0	0.00430	0.01065	0
GEAR LUBRICATING OIL	103553	0.51062	0	0.06945	0.17182	0
LUBRICATING OIL	103553	11.2234	0	0.01305	0.03230	0
AIRCRAFT CLEANING	104579	77.5144	0	0.09393	0.23238	0
HYDRAULIC FLUID	105648	32.34	0	0.574	1.42	0
CLEANING COMPOUND,	118171	5.1777	0	0.00645	0.01597	0
SCALE REMOVING COMPOUND	121387	30.161	0	0.01435	0.0355	0
CLEANING COMPOUND	123780	8.70651	0	0.00783	0.01938	0
GUN SOLVENT	100418	0.2298	0	0.00574	0.0142	0
INSTAPAK PART CLEANER	104001	0.072	0	0.2296	0.568	0
INSTAPAK 100 FOAM KIT	200672	483.84	0	20.664	51.12	0
FREON 13	00F000	1.343	0	0.24395	0.6035	0
CITRIKLEEN	00F002	0.55704	0	0.03788	0.09372	0
WELDING RODS	3439SE	7.644	0	0.3444	0.852	0
WD-40	LOCAL	0.3016	0	0.02296	0.0568	0
N-HEXYL CARBITOL	LOCAL	0.02485	0	0.00143	0.00355	0
NITRIC ACID	LOCAL	0.0959	0	0.00143	0.00355	0
SURFURIC ACID	LOCAL	0.02735	0	0.00143	0.00355	0
TRIMETHYLPENTANE	LOCAL	0.02215	0	0.00143	0.00355	0
ACRYLIC EPOXY	LOCAL	134.745	0	1.8655	4.615	0
MX/MG CARRIER	LOCAL	5.57425	0	0.07892	0.19525	0
HYDROCHLORIC ACID	LOCAL	0.0987	0	0.00143	0.00355	0
KARL FISCHER REAGENT	LOCAL	0.9006	0	0.01722	0.0426	0
EVERCOAT MARINE RESIN	P8300	0.0303	0	0.00287	0.0071	0
DEVELOPER	PZP13A	3.265	0	0.07175	0.1775	0
RINSOLVE 140	RINSOL	685.1	0	6.3427	15.691	0

Required Inputs

Total Point Estimate	TOTAL	TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
$7,109,994	$6,985,	$79	$113,98	$0	$0	$0
3.44%	#produc		#produc			
$7,362,920						

Substance Name	Persona	Legal	Medical	Facilitie	Support	Emerge
TRICHLOROETHANE 1.1.1	10211.0	0.00229	255.403	0	0	0
LUBRICATING OIL	345640.	0.084	353.635	0	0	0
EPOXY PRIMER COATING	66818.8	0.54080	928.293	0	0	0
PHOTOGRAPHIC FIXING BATH	30599.8	0	928.293	0	0	0
GREEN LACQUER PAINT	89854.9	0.0747	1281.92	0	0	0
LACQUER	186157.	0.31428	825.15	0	0	0
LACQUER	133585.	3.42684	255.403	0	0	0
EPOXY RESIN	0	0.0005	1092.55	0	0	0
CORROSION PREVENTIVE	29701.2	0.3645	5390.98	0	0	0
GREASE	59362.7	0.43052	5872.31	0	0	0
HYDRAULIC FLUID	350251.	8.31942	353.635	0	0	0
HYDRAULIC FLUID	368940.	0.92484	611.222	0	0	0
REPLENISHER/DEVELOPER	29982.9	0	611.222	0	0	0
LUBRICATING OIL	31928.2	2.06113	1182.47	0	0	0
CLEANING COMPOUND	50370.2	0.0675	255.403	0	0	0
ADHESIVE	108584.	0.45763	255.403	0	0	0
PAINT, THIN, ALIPH	18333.4	0.54936	846.307	0	0	0
PAINT, POLY, BLACK	17634.6	0.01705	275.05	0	0	0
ACETONE	222549	3.71556	275.05	0	0	0
ENGINE OIL	12792.5	0.00113	481.337	0	0	0
GREASE	12993.5	0.00230	98.2321	0	0	0
FLUX, SOLDERING	32482.8	0.00556	5157.18	0	0	0
ACETIC ACID	9843	0.00384	825.15	0	0	0
HYDRAULIC FLUID	310010.	3.53908	611.222	0	0	0
AROMATIC NAPTHA	119402.	0.00015	336.172	0	0	0
CORROSION PREVENTATIVE	32845.2	0.04556	4675.85	0	0	0
CORROSION PREVENTIVE	77436.1	0.486	275.05	0	0	0
LUBRICATING OIL	245077.	0.27123	4931.25	0	0	0
ENGINE OIL	13561.1	0.00046	336.172	0	0	0
CORROSION PREVENTIVE	260972.	0.1458	336.172	0	0	0
CORROSION PREVENTIVE	36826.8	0.0108	255.403	0	0	0
CORROSION PREVENTIVE	35958.4	0.01215	275.05	0	0	0
LACQUER	23731.6	0.01919	275.05	0	0	0
SODIUM BICARBONATE	0	1.62	846.307	0	0	0
ELEC. FOR BATTERY	18627.3	0.048	255.403	0	0	0
PETROLATUM, TECHNICAL	0	0.51005	255.403	0	0	0
CLEAR LACQUER	0	0.00126	275.05	0	0	0
RED LACQUER	17634.6	0.00532	98.2321	0	0	0
BORIC ACID	16401.7	0.05404	4675.85	0	0	0
CHLOROBENZENE	27676	0.00000	5390.98	0	0	0
CORROSION PREVENTATIVE	250920	0.06075	1100.2	0	0	0
METHANOL (METHYL	702914.	0.00003	98.2321	0	0	0

66

Substance Name	Persona	Legal	Medical	Facilitie	Support	Emerge
ACETONE	73897.1	0.00002	947.394	0	0	0
TOLUENE	9435	0.00226	846.307	0	0	0
CORROSION PREVENTIVE	103577.	0.07897	275.05	0	0	0
METHYL ETHYL KETONE	0	11.1339	825.15	0	0	0
CARBON REMOVING	18098.7	0.00350	275.05	0	0	0
ISOPROPYL ALCOHOL	63304.7	0.22859	2097.25	0	0	0
NAPTHA COMPASS FLUID	13435.8	0.0036	255.403	0	0	0
PNT, AEROSOL, BLK, ENAMEL	0	0.03306	275.05	0	0	0
PRIMER COATING	17634.6	0.05451	275.05	0	0	0
LUBRICATING OIL	12315.5	0.00558	432.221	0	0	0
SEALING KIT	0	0.006	846.307	0	0	0
LUBRICATING OIL, GENERAL	73022.3	0.29910	928.293	0	0	0
STABOND HT-11 SEALENT	0	0.0015	3713.17	0	0	0
SC-840	94698.7	0.10893	275.05	0	0	0
CORROSION PREVENTIVE	102365	0	275.05	0	0	0
1,1,1-TRICHOROETHANE	0	0.14814	481.337	0	0	0
CLEANING COMPOUND	13938.0	0	1360.51	0	0	0
CLEANING AND LUBRICATING	0	0.62025	98.2321	0	0	0
LACQUER	0	2.60406	928.293	0	0	0
METHANOL	10009.3	0.03120	846.307	0	0	0
ENAMEL	0	0.04043	275.05	0	0	0
CLEANING COMPOUND	107597	0.02881	275.05	0	0	0
SCALE REMOVING COMPOUND	18343.1	0.00018	481.337	0	0	0
ANTIFREEZE	12413.9	0.00981	846.307	0	0	0
ADHESIVE	25659.4	0.02636	846.307	0	0	0
LAYOUT DYE	71635	0.01876	1203.34	0	0	0
CORROSION RESISTANT	91079	0.28765	481.337	0	0	0
YELLOW LACQUER PAINT	89497.4	10.1264	1327.64	0	0	0
LACQUER	25545.3	1.59048	846.307	0	0	0
ADHESIVE	0	0.03341	481.337	0	0	0
SEALING COMPOUND	71575	0.003	98.2321	0	0	0
LUBRICATING OIL	25987.7	0.00042	275.05	0	0	0
FREON TF	0	10.4663	611.222	0	0	0
ENGINE OIL	0	0.58700	353.635	0	0	0
LUBRICATING OIL	31694.2	0.00982	255.403	0	0	0
INSPECTION PENETRANT KIT	34606.4	0.18034	373.282	0	0	0
ALODINE COATING	22897.0	0.08006	611.222	0	0	0
	25297.2	0	481.337	0	0	0
CORTEC VCI-560	40424.2	0.00045	846.307	0	0	0
SILICONE COMPOUND	0	0.03921	432.221	0	0	0
DENT FILLER	73459	0.0165	5390.98	0	0	0
LUBRICATING OIL, GENERAL	71403	0.0063	98.2321	0	0	0
AIRCRAFT GREASE	340549.	0.10505	825.15	0	0	0
HYDRAULIC FLUID	9435	0.22176	432.221	0	0	0
SILICONE	51870.4	0.5322	432.221	0	0	0
PNT, AEROSOL, ORANGE, LAC	71386.5	0.01514	432.221	0	0	0
LACQUER	71315	0.23076	611.222	0	0	0

Substance Name	Persona	Legal	Medical	Facilitie	Support	Emerge
AIRCRAFT TURBINE LUBE OIL	31174.2	0.084	275.05	0	0	0
GREASE	32086.2	0.16615	275.05	0	0	0
HYDRAULIC FLUID	22851.5	0.07257	255.403	0	0	0
LACQUER	71865	0.00018	611.222	0	0	0
PAINT STRIPPER	14148.6	0.45	353.635	0	0	0
PAINT, POLY, GREEN	17634.6	0.04568	275.05	0	0	0
INSPECT PENETRANT	30102.1	0.00202	275.05	0	0	0
GEAR LUBRICATING OIL	12315.5	0.02032	255.403	0	0	0
LUBRICATING OIL	12760.1	0.00382	4675.85	0	0	0
AIRCRAFT CLEANING	18116.3	0.04418	275.05	0	0	0
HYDRAULIC FLUID	281392.	1.008	275.05	0	0	0
CLEANING COMPOUND,	14381.7	0.00067	275.05	0	0	0
SCALE REMOVING COMPOUND	14333.1	0.0048	336.172	0	0	0
CLEANING COMPOUND	13864.2	0.00081	336.172	0	0	0
GUN SOLVENT	0	0.0006	336.172	0	0	0
INSTAPAK PART CLEANER	0	0.024	275.05	0	0	0
INSTAPAK 100 FOAM KIT	0	7.2	275.05	0	0	0
FREON 13	0	0.1275	825.15	0	0	0
CITRIKLEEN	0	0.00396	1239.23	0	0	0
WELDING RODS	0	0.2268	98.2321	0	0	0
WD-40	0	0.00672	98.2321	0	0	0
N-HEXYL CARBITOL	0	0.00015	98.2321	0	0	0
NITRIC ACID	0	0.00048	98.2321	0	0	0
SURFURIC ACID	0	0.00048	3713.17	0	0	0
TRIMETHYLPENTANE	0	0.00015	353.635	0	0	0
ACRYLIC EPOXY	0	0.65	98.2321	0	0	0
MX/MG CARRIER	0	0	98.2321	0	0	0
HYDROCHLORIC ACID	0	0.0048	846.307	0	0	0
KARL FISCHER REAGENT	0	0.0018	353.635	0	0	0
EVERCOAT MARINE RESIN	0	0.00036	1347.96	0	0	0
DEVELOPER	0	0	98.2321	0	0	0
RINSOLVE 140	0	0.663	5390.98	0	0	0

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He entered the United States Air Force Academy in 1981 and graduated in 1985 after earning a Bachelors of Science degree in Computer Science. After completing Undergraduate Pilot Training at Williams Air Force Base in Phoenix, Arizona, he was stationed at Charleston Air Force Base, South Carolina where he flew the C-141B aircraft.

Captain Garner holds a senior pilot rating with over 3000 hours of flying experience and has held air-refueling qualified aircraft commander qualifications in the C-141B and instructor and flight examiner qualifications in the C-21A. He completed Squadron Officers School in residence in the Summer of 1990.

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13. ABSTRACT (Maximum 200 words)

This research effort developed a modification to the HAZMAT program so that the program could provide the user with the capability to generate an estimate during the concept exploration and design phases for the total costs associated with hazardous materials usage in a major weapon system. Using the HAZMAT database, a spreadsheet was developed which projects a cost for a weapon system based on its total surface area and the number of aircraft to be produced by performing an analogy with a similar weapon system. The modification uses algorithm which are based on the hazardous material substances rather than processes which use hazardous materials. This enables the user to eliminate various substances entirely from the weapon system rather than trying to identify every process which uses a particular substance.

The modification was identified to be the most efficient method of calculating an estimate during the early phases of the life cycle through in depth interviews and analysis of existing literature on the subject. The authors feel that the methods discovered in this thesis will provide insight for future revisions of HAZMAT and new attempts to formulate a life cycle cost model for hazardous materials.

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